OPERATION OF THE 300-kW CAPACITOR
TEST FACILITY

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Summary

Pressing needs in several contemporary power, military, and scientific areas have put severe requirements on power conditioning components. In an effort to advance the state of the art, component selection and development tests were collected into a major proposal in 1978-79 at Los Alamos National Laboratory by three interested divisions. One significant portion of that proposal created the 300-kW Capacitor Test Facility (CTF). This paper is the first report of the facility operation and results.

Facility History

The original charter of the facility was first to study and compare the best capacitor technologies available for devices with highest lifetime and energy density for repetitive pulse service. Once a selection was made, further development of that technology would be pursued. By 1980, it was discovered that device development was already under way at Sandia National Laboratories (Albuquerque, New Mexico). Fortunately, joint efforts between the two Laboratories began that year with perfect compatibility of facility development. Sandia[1],[2] had developed a highly sophisticated manufacturing capability and technology; Los Alamos had spent their efforts on development of a test and diagnostic facility.

Both Laboratories' products have matured. The original task (selection of a superior capacitor technology) given Los Alamos has been met. There is no manufactured device available on the market that can compete with the Sandia perfluorocarbon capacitor on the basis of energy density and lifetime for repetitive pulse power applications.

The facility has now been in operation for 10 months. Data are flowing on a daily basis, creating new needs for instrument development.

Los Alamos Test Facility

The Los Alamos test facility was fabricated using internal supporting research funding for the purpose of developing pulse power components, including energy storage capacitors. The CTF has a large oil submersible platform, a 300-kW high-voltage power supply, and a 1.2-MW cooling tower. The platform is fitted with the necessary switching electronics to resonantly charge and then rapidly discharge a test capacitor bank. This charge/discharge cycle can be varied from a single shot to a 1-kHz repetition rate.

The major elements of the system are listed below.

o CTF modulator and power system including cooling tower
o Screen room and diagnostics facility
o Tektronix data collection system and signal processing package
o Biddle partial discharge analyzer (PDA)

The CTF test platform is mounted on a scissor jack providing at least 55 in. of lift with a load limit of 4500 lb. The platform and jack are mounted in a 6- x 9- x 5-ft tank with a capacity of 2000 gallons of dielectric oil. The platform has a top cover that rests on the tank ridge when the jack is collapsed. This position fully encloses the electronics (modulator), reducing electromagnetic interference (EMI) to the rest of the facility. This lowered position also submerges the modulator apparatus in the dielectric oil.

The modulator sections operate independently. One section, configured as a series switch, is isolated from ground and triggered optically. The switch element is an EG&G HY-36 triode thyratron that switches current through a charge inductor (0.4 H) and series diode to the capacitor bank. The bank capacitance and charge inductor form a resonant network that will charge to approximately twice the supply voltage. The second section of the CTF modulator is a shunt switch for rapid discharge of the capacitor bank. Either an EG&G HY-5 or HY-7 thyratron can be used, depending on the test needs. All bias and supply voltages are available to operate either tube.

The capacitor bank includes five load resistors (∿8 Ω each) capable of dissipating 30 kW each and of providing a support jig for the capacitors. The complex impedance of these load resistors remains mostly resistive up to ∿30 MHz. There is a parallel resonance at 73 MHz with an impedance of only 200 Ω. The present system speed (>100 ns) is such that the complex character will not present any significant problems. Because a complex impedance plot (Smith chart) exists for these devices, future CTF adaptations can be compensated for if necessary.

The data collection system consists of the Tektronix signal processing system and 7612D transient digitizer. The signal processing system uses Tektronix CP-4165 (PDP-11) hardware and a 4010 graphics terminal. The disk-based software consists of the Tektronix SPS Basic signal processing and graphics routines.

Temperature Monitoring System

Early capacitor failure data indicated subtle evidence of temperature sensitivity with the perfluorocarbon capacitors. We determined that case temperature measurement was crucial to the overall effort. The measurement had to be made on the capacitors during circuit operation with data available in real time. We designed a system that isolates the temperature probe optically from processing and recording instrumentation. This system has a reponse of 50°C per minute, accuracy of ±2%, and repeatability of about 0.1%. Data are sent to the screen room instrumentation via a fiber-optic line. Thus, the high-noise environment of the pulse discharge circuitry is isolated from the more sensitive instruments. Figure 1 shows the "power on" case temperature transient of a typical perfluorocarbon-impregnated (Sandia) capacitor. Figure 2 shows the thermal transient of a typical MIPB-impregnated capacitor.

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The thermometer system output from the opto-receiver is an analog voltage related to the probe temperature by the function shown in Figure 3. Because data processing capability is available in the screen room, no attempt is made to linearize the analog section.

Analysis of the step-power thermal transient (on or off) and case temperature vs various power levels can also be done with the same data processing equipment (Tektronix CP-4165/PDP-11/34). Our goal is to be able to develop an accurate thermal model of the device under test.

Because of critical manufacturing details, these two capacitors are not ideal for comparison. The foil/film wrap of the MIPB capacitor is much tighter, limiting the flow of impregnant from central areas of the heat generating bulk. Also, this particular MIPB-filled capacitor uses a stacked array on the same film. That is, the four foils are distributed across the film on both sides to create three series capacitors on the same film. This method, although reducing stress, creates a central region with limited transport mechanism to remove the heat. The result of this limited transport system (and of the reduced MIPB heat capacity) is demonstrated in Figs. 4 and 5. The sharp rise and fall of the case temperature of the perfluorocarbon type is good evidence of a superior thermal management system.

The high mobility and heat capacity of the perfluorocarbon impregnant have demonstrated the importance of having a known model and of the thermal management system in high-repetition-rate pulse power applications. Typical switching transients in pulse power systems manifest both the classical stress losses of dielectrics and the high-frequency components that are products of the switching system. These high-order components can be responsible for skin losses in the foils and rf-related additional losses in the dielectrics.

It is a necessary and central issue to consider the heat transport mechanisms and overall thermal management in the design of high-energy-density, high-repetition-rate, long-life storage capacitors, especially with densities of 50 J/lb.

Charge Noise Evaluation

Charge noise (or partial discharge) information has been used in the past as an indication of destructive partial discharge activity in capacitor testing. Others[3,4] have shown that repeated, localized partial discharges in a capacitor structure consitute one of the prime failure mechanisms of the dielectric. Indeed, this is true of all commercially available capacitors for pulse power. This phenomenon can occur in the margin area where enhancement due to foil edge geometry increases nonhomogeneous stresses on the dielectric. As bulk stress rises, these enhanced regions become the weak link in the chain. Manufacturing errors such as wrinkles, folds, and voids also cause many lifetime failures.

Because of the general interest in charge noise evaluation, we obtained a PDA from the James G. Biddle Co. (Plymouth Meeting, Pennsylvania). This analyzer includes a low-noise power supply capable of providing up to 250 kV, a discharge noise detector with better than 5-pC sensitivity, and a Tracor Northern Model 1750 pulse height analyzer with a disc recorder. This system can display 1 part in 10^{12} charge noise product.

Because of the exceptional quality and chemical make-up of the Sandia perfluorocarbon cpacitors, the PDA has been able to measure some interesting characteristics. The perfluorocarbon impregnant is apparently responsible for a unique and well-defined noise peak that has been observed on the pulse height analyzer. This peak (Fig. 6) indicates statistically

that 85 to 90% of the noise spikes (during a charge to 5.4 kV/mil stress) fall within a narrow domain at about 5 pC. One explanation of this phenomenon is that a charge is being injected into the perfluorocarbon impregnant. This is more or less verified by the fact that all three tested dielectrics (polysulfone, polypropylene, polycarbonate) have shown identical spectral signatures. The impregnant is the only constant among the three capacitors.

One very distinct characteristic of these perfluorocarbon capacitors is the lack of any perceptible charge noise on measurement cycles following the first charge cycle. If a period of several hours has transpired between charges or a voltage reversal (opposite polarity charge) has occurred, then charge noise is visible again. On charge cycles immediately following other charge cycles of the same polarity, there appears to be little or no charge noise. Hydrocarbon-impregnated capacitors do not demonstrate the same magnitude of difference. Figure 7 shows repeated charges of a hydrocarbon-impregnated capacitor (4 cycles, 30 seconds apart). Figure 8 shows the results when a Sandia capacitor is cycled exactly the same.

One explanation for the disappearance of the charge noise described above is that the perfluorocarbon impregnant has a long-term charge storage capability. This long-term storage may be responsible for a space-charge effect at the foil edges. This almost creates a guardwire effect forcing enhancement back into a more film-normal homogeneous field reducing the thermal erosion in the margin area experienced in capacitors of different impregnant types.

Our comparisons of the two types of capacitors were limited by the inability of any of the commercial capacitors to exceed 1400 V/mil stress without internal breakdown. In the above comparison of consecutive charge, the stress in the Sandia perfluorocarbon capacitor was held to 2 kV/mil. They routinely undergo 5.4 kV/mil charges during our low power tests without problem.

In Fig. 9, a multichannel scan shows the charge noise vs time for one of the Sandia capacitors stressed to 5.4 kV/mil. In Fig. 10, the second consecutive charge is shown 30 seconds later. The scan time is 25.6 seconds, and the same machine parameters were used. We assume that similar charge injection noise would be visible with the hydrocarbon impregnants; however, no commercial capacitors were available that would allow these high stresses on the dielectric system. Breakdowns in the insulator stud areas and dielectric punch-through because of folds and wrinkles in the bulk occurred well before 2 kV/mil was reached. We expect the next few months to be quite instructive in the area of charge noise phenomena as our equipment becomes more sophisticated.

Electrical Modeling

In most pulse application service, the current risetime through a typical storage capacitor would be probably 1 μs to about 100 ns (thyratron and SCR switched systems). An average of 400 ns would have the Fourier equivalent of about 900-kHz bandwidth. A value of 1 MHz was chosen for network modeling of these Sandia capacitors. We felt that this value would give a realistic view of the lumped effect of effective series resistance (ESR) and parasitic inductance for power loss characterization. A parallel network of the capacitor and of a strap inductor is resonated near 1 MHz using an HP-4815A vector impedance meter.

Several impedance measurements over the range of 500 kHz to 100 MHz plus an indicated series self-resonance of the capacitors result in a model of the Sandia capacitor. The device is characterized by a series LRC network. These devices show about 30-nH

inductance, approximately 35-mΩ resistance, and about 0.2-μF capacitance. Both the ESR and the inductance have proved to be extremely stable throughout all 80 odd units tested so far. Consistency of the capacitance value has characteristically been to a few tenths of a percent of any one dielectric type.

It has been our experience so far with the perfluorocarbon (Sandia) capacitors that the ESR at 1 MHz and the parasitic inductance have not shown any significant change with life tests at well over 2×10^8 shots at 1-kHz repetition rate and 3.5-kV/mil stress.

<div align="center">Conclusion</div>

The CTF at Los Alamos National Laboratory is now functional. We are verifying daily the need for thermal design considerations in moderate-to-high repetition rate capacitors. The perfluorocarbon impregnated, Sandia capacitors have proved to be worthy of continued development effort. Our instrumentation and testing program is maturing with each test series. The next year will yield significant advances in both testing instrumentation and in the quality of the capacitors being studied.

Funding Souce

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References

1. Mauldin, G. H., "The High-Energy-Density Capacitor Program at Sandia National Laboratories," Proc. Nas/ICCC Symposium on High-Energy-Density Capacitors and Dielectric Materials, Boston, Massachusetts, October 28, 1980.

2. Mauldin, G. H., "The Application of Perfluorocarbons as Impregnants for Plastic Film Capacitors," Proc. NASA/IEEE Symposium, Huntsville, Alabama, February 24-25, 1981.

3. Bickford, K. J., Mauldin, G. H. and Sarjeant, W. J., "Advanced Development of Electrical Energy Storage Components for High Reliability Applications," Proc. 3rd IEEE International Pulse Power Conference, Albuquerque, New Mexico, June 1-3, 1981.

4. Parker, R. D., "Design and Failure Mechanisms of High-Energy-Density Capacitors Operating at High Repetition Rates," Proc. NAS/IEEE Symposium on High-Energy-Density Capacitors and Dielectric Materials, Boston, Massachusetts, October 28, 1980.
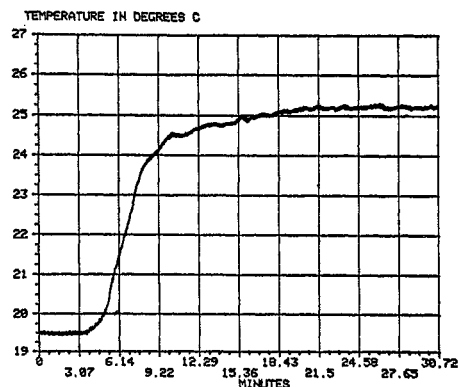
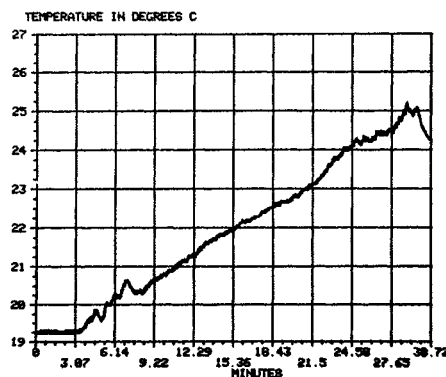Fig. 1. FC-72 filled power-on temperature rise
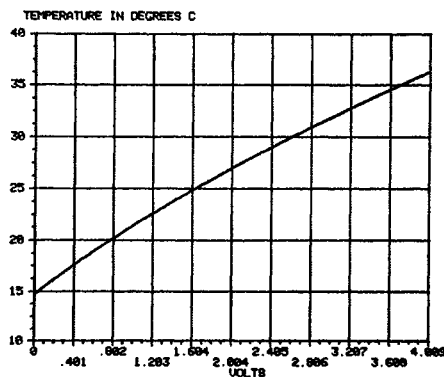

Fig. 2. MIPB filled power-on temperature rise.
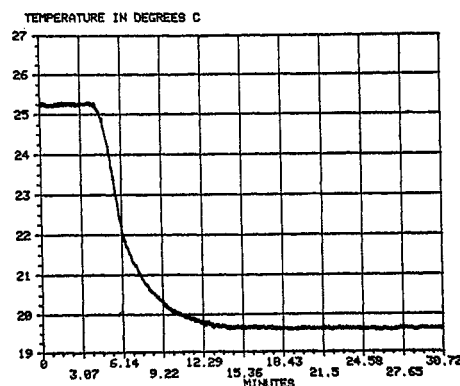

Fig. 3. Thermometer system function.

Fig. 4. FC-72 filled cool-down.

Fig. 5. MIPB filled cool-down.
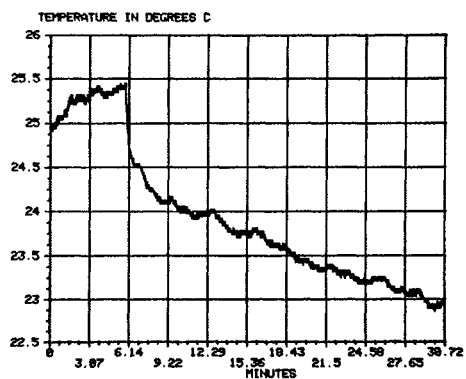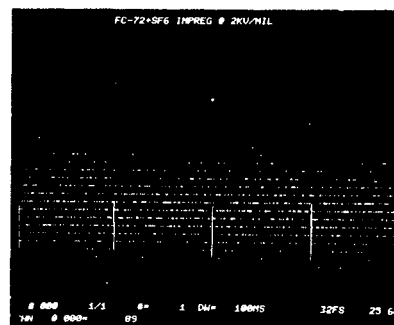

Fig. 6. FC-72 filled noise spectrum.

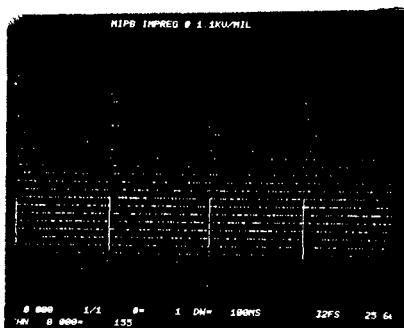
Fig. 7. Multiple charge, MIPB capacitor.

Fig. 8. Multiple charge, FC-72 capacitor.
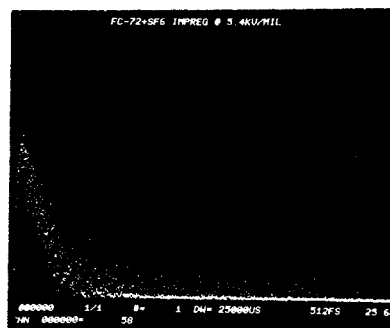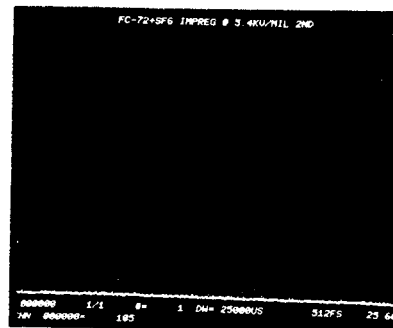

Fig. 9. First charge, FC-72 filled capacitor

Fig. 10. Second charge, FC-72 filled capacitor.